Indirect evidence for the structure of the earth

There is limited direct access to the rocks within the Earth and so indirect methods of observation such as: **remote sensing** methods, which are provided by seismic waves; **density data** and **meteorite evidence**, which infer the nature of the deeper layers of the Earth.

Seismic (earthquake waves)

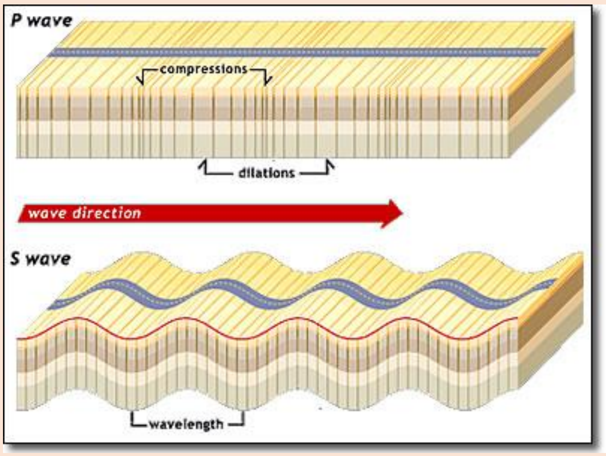
Vibrations from earthquakes are detected by **seismometers** and are shown on **seismograms** (**seismographs**) all around the world.

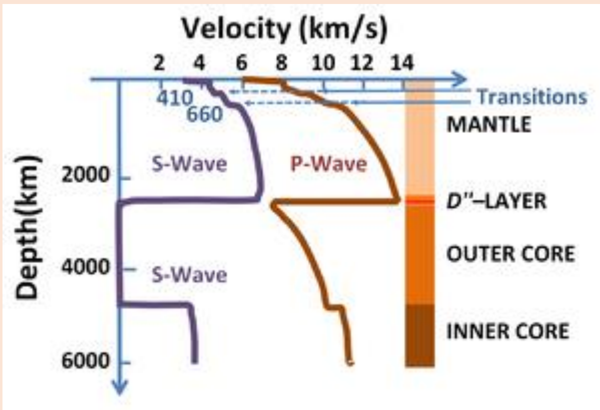
Analysist of earthquake history over the past 100 years has helped build up a picture of the Earth's structure.

Body waves

P and S waves are seismic waves that can travel through the earth so are named body waves.

- When the rock is more rigid and incompressible then they will speed up
- When the rock is more dense they travel slower since the vibrations occur more frequently so energy is lost over shorter distances.





If the **rock loses its rigidity completely** then **p waves slow down** but **s waves will slow down** and **stop completely**.
S waves can't travel through **liquids** (like the ocean or more importantly the **outer core**). They wills top at a depth of **2900km**, the boundary between the outer core and mantle named the **Gutenberg discontinuity.**

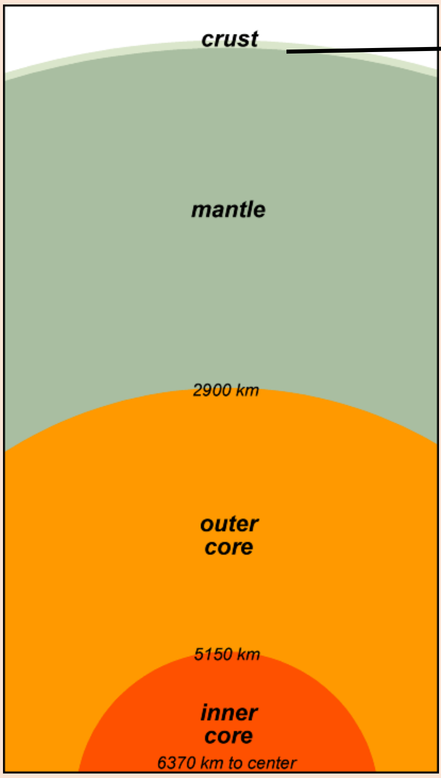
In 1909, Andrija Mohorovicic found that seismic velocities vary (7.1 km/s to 8.1 km/s) at the Moho (short for Mohorovicic Discontinuity) showing that the rigidity, incompressibility and density of rocks the other side is different.

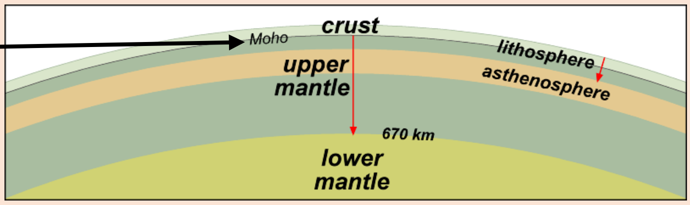
The Moho is a few km below the surface (~ 20 to 70km for continental and ~7km for oceanic). The seismologist also discovered that, for one earthquake, two pulses were received at one seismograph.

He suggested the seismic waves travelled by two different routes.

1. One **above the boundary (Moho),** where the **seismic waves** take a **slower route** through the **crust.** This route is slower as the rocks are **less rigid and less incompressible.**
2. One **below the Moho boundary**. This **deeper, long path** sees the seismic waves arrive first (**travel faster)** as the rocks are **more rigid and incompressible**.

The varying velocities of P and S waves are shown on the seismographs and are sued to determine properties and location of boundaries between layers.





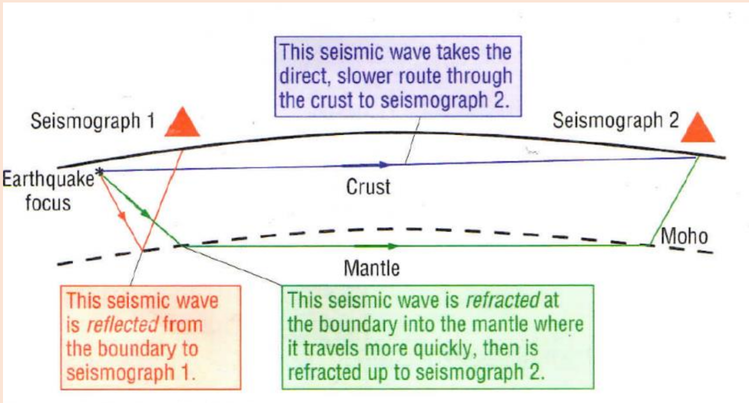


Figure 2 Finding the Moho

Important changes in velocity through the earth

3. Both **P and S waves slow** down in the **asthenosphere** because the **1% to 5% partial melting reducing rigidity** of rock.

4. Both **P and S waves speed up** through the **mantle** as the **pressure increases** and the **rock becomes more incompressible**.

5. **P waves suddenly slow** down at the **Gutenberg Discontinuity (2900km**) as they enter the **liquid outer core** where the **rigidity is low**. **S waves stop completely** as they **cannot be transmitted** in a liquid.

6. At the **solid inner** core (**Lehmann Discontinuity, 5100km depth)**, **P waves speed up** as **rigidity** and **incompressibility have increased**. S waves are propagated at 90^0 to the P waves.

The Shadow Zone

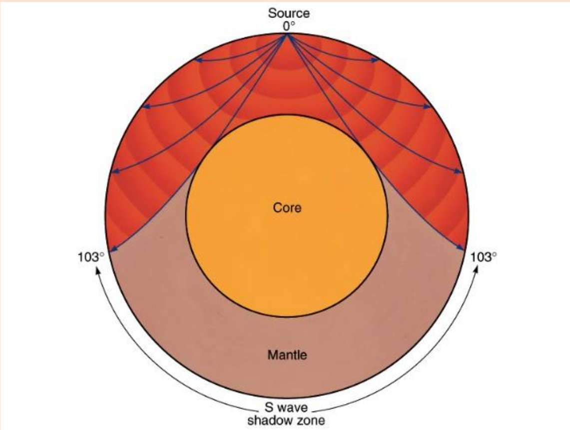
Shadow zone = the large distances from the focus at which both P and S waves can't be detected (103^0 to 142^0) while the S wave shadow zone extends further (103^0 to 103^0).

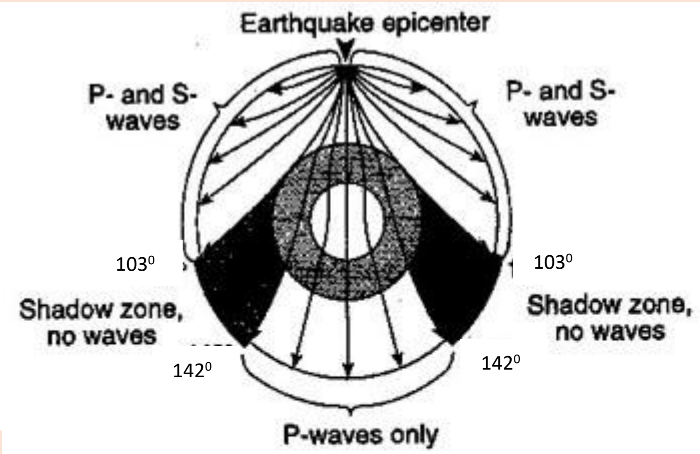
In 1906, Richard Oldham discovered this zone as large earthquake body waves were not recorded in these latitudes from the focus.

Seismic waves (in particular **P waves)** are **refracte**d at the **Gutenberg Discontinuity (2900km depth**), marking the edge of the **outer core**.

The wave reaching **102^0 from the focus is not affected**. Waves between **103^0 and 142^0**, P **waves are refracted** and **S waves stop**, as they can't transmit through liquids, at the discontinuity creating a zone where there are **no P and S waves**.

Beyond the zone of 142^0, S waves still can't be detected as they can't pass through liquid outer core **but P waves can** however they **slow down** (take long to arrive) since there is a **loss of rigidity and incompressibility** in liquid outer core.





P waves slow down through outer core but arrive quicker than expected since they speed up in the inner core suggesting the inner core must be solid rigid, more incompressible material than the liquid less rigid and less incompressible outer core. ANGLES RECORDED FROM FOCUS/EPICENTRE

In 1936, Inge Lehmann suggested that the inner core may be solid due to the very high pressures. The phase boundary was named after her (between outer and inner core is called the Lehmann Discontinuity @ 5100km).

She predicted that S waves are generated (by P waves) in the inner core and travel through the solid inner core. This was possible to test by analysing seismic waves from hydrogen bombs set off at precisely known time and location.

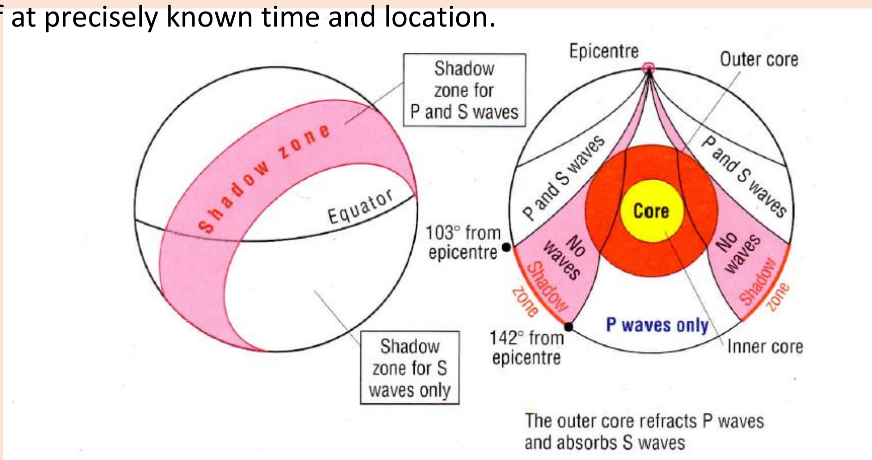


Figure 3 The shadow zone

Density

- The **average density** of the Earth: **5.5 g/cm^3.**
- The density of rocks making up the **continental crust: 2.7g/cm^3**
- The density of the rocks making up the **oceanic crust: 2.9 g/cm^3**

To account for the density of the earth, the **density of the core must be high**. There is a clear **increase in density with depth**, especially at the **core boundary** (2900 Km and up). It is theorised that the composition becomes **iron and nickel.**

Examiner tip

In general, the velocity of seismic waves increases with depth. So does density. It is a common mistake to say that wave velocity increases *because* the density increases. In fact, they travel faster due to the increase in incompressibility.

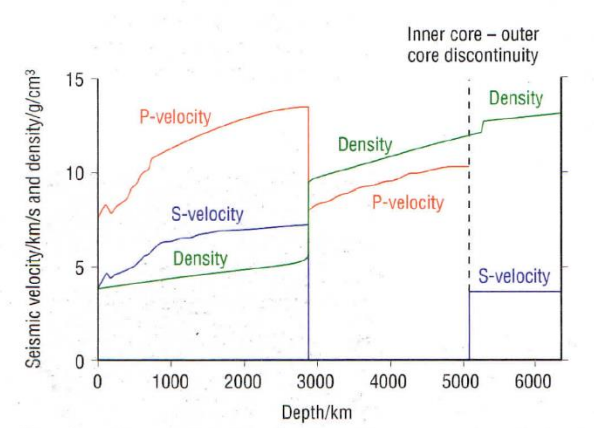


Figure 1 Change of density and P and S wave velocity with depth

Extra-terrestrial meteorites

The Earth shares common origin with other planets and debris left over from the formation of the Solar System.

Frequently, microscopic-small-(and sometimes) large fragments of debris fall o the Earth as meteorites; however, most burn up as they pass through the atmosphere.

Meteorites will not be the same as the Earth's crustal rocks; influenced by weathering and erosion, metamorphism and other changes. Meteorites may share similarities with the core or the composition of the mantle.

Of the two types of meteorites, iron meteorites are denser and this suggests they are similar to the core. Whereas, less dense meteorites are probably similar to the mantle.

Figure 4 Part of a 20-tonne iron meteorite from Greenland with a composition of 89% iron, 8% nickel, 2% sulfur

Stony meteorite

- Density: 3.0 to 3.7 g/cm^3
- Composition: silicate minerals similar to peridotite
- Comparison: similar to the Earth's mantle

Chondrites are stony meteorites with small globules of olivine and a little carbon; they probably represent an overall composition for the Earth.

Key meteorite facts

Metallic meteorites

- Density: 7.0 to 8.0 g/cm^3
- Composition: iron and nickel with some sulfur and silicon minerals
- Comparison: similar to the Earth's core